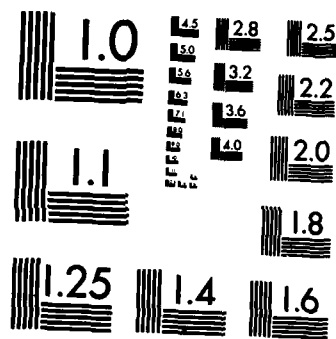


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ELECTRICAL ENGINEERING A ISHIMARU MAR 83 TR-5-ONR
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AD A 126010

DEPARTMENT OF ELECTRICAL ENGINEERING
University of Washington
Seattle, WA 98195

Annual Summary Report
by
Akira Ishimaru

March 1983

MULTIPLE SCATTERING EFFECTS ON TRANSMISSION THROUGH THE ATMOSPHERE

ONR Contract N00014-78-C-0723

September 1, 1982 to August 31, 1983

Dr. B. R. Junker, Contract Monitor
Code 421
Director, Physics Program
Physical Sciences Division
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

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		6. PERFORMING ORG. REPORT NUMBER
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Transmission of optical waves through atmosphere, multiple scattering effects, fog, clouds, rain, hail, snow, Monte-Carlo solution, turbulence, diffusion of light pulse, radiative transfer theory, forward scatter theory, beam waves, Henyey-Greenstein scattering pattern, angular broadening, pulse broadening, coherence bandwidth, coherence time.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) -This annual report gives a summary of the work completed and underway on the contract covering the period from September 1, 1982 to March 31, 1983. The work is directed to the investigation of the transmission characteristics of optical waves with wavelengths in the range of 1-15 μ m through various atmospheric conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers. Progress was made on the thorough understanding of polarized wave transmission characteristics through fog.		

1. Principal Investigator: Akira Ishimaru

2. Contract Description

This contract is directed to the investigation of the transmission characteristics of a wave with the wavelengths in the range of $1\text{ }\mu\text{m}$ to $15\text{ }\mu\text{m}$ through various atmospheric conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers.

3. Scientific Problem

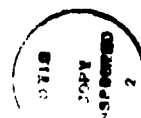
We have made some significant progress on the study of wave transmission characteristics through a diffuse medium. In the coming year, we will concentrate on the polarization effects due to nonspherical scatterers, the pulse propagation characteristics, and the effects of a finite beam. We will also develop numerical methods for various cases to arrive at useful transmission codes.

4. Scientific and Technical Approach

We have successfully used the matrix eigenvalue technique and extended it to include the Stokes vectors and polarization effects. We also developed formulations to include the pair-correlation between particles in a dense scattering medium. We also need to develop the technique to handle nonspherical particles.

5. Progress

For the past years, we have made significant progress in the understanding of the transmission characteristics of a wave through the atmosphere. We have completed the calculation of the exact transmission characteristics of plane optical waves through fog in the wavelengths of $0.5\text{ }\mu\text{m}$ to $15\text{ }\mu\text{m}$ based on the matrix eigenvalue technique, including polarization effects. We also clarified the characteristics of the coherent field in a dense medium. We are now in the process of developing general formulations for nonspherical particles.



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6. Publications

Journal Publications with ONR Sponsorship

1. "Backscattering of a picosecond pulse from densely distributed scatterers," Applied Optics, 18:20, pp. 3484-3488, October 1979; coauthors, K. Shimizu, L. Reynolds, and A. P. Bruckner.
2. "Backscattered pulse shape due to small-angle multiple scattering in random media," Radio Science, 15:1, pp. 87-93, January-February, 1980; coauthor, K. J. Painter.
3. "Multiple-scattering effect on radiometric determination of rain attenuation at millimeter wavelengths," Radio Science, 15:3, pp. 507-516, May-June 1980; coauthor, R. Cheung.
4. "An experimental test of the reduced effective velocity of light in a diffuse medium," Optics Letters, 5:5, pp. 205-207, May 1980; coauthor, K. Shimizu.
5. "Multiple scattering effects on wave propagation due to rain," Annales des Télécommunications, 35, pp. 373-379, November-December 1980; coauthor, R. Cheung.
6. "Theory of optical propagation in the atmosphere," Optical Engineering, 20:1, pp. 63-70, January-February 1981.
7. "Theoretical and experimental study of transient phenomena in random media," Proceedings, Symposium on Multiple Scattering and Waves in Random Media, ed. by P. L. Chow, W. Kohler, and G. Papanicolaou. North-Holland Publishing Co., Amsterdam, 1981.
8. "Attenuation constant of coherent field in a dense distribution of particles," Journal of the Optical Society of America, 72:10, pp. 1317-1320, October 1982, coauthor, Y. Kuga.
9. "Transmission, backscattering, and depolarization of waves in randomly distributed spherical particles," Applied Optics, 21:20, pp. 3792-3798, October 1982; coauthor, R. Cheung.
10. "Scattering and diffusion of a beam wave in randomly distributed scatterers," Journal of the Optical Society of America, 73:2, pp. 131-136, February 1983; coauthors, Y. Kuga, R. Cheung, and K. Shimizu.

6. Publications - continued

Paper Presentations Related to the Contract Since September 1978

1. A. Ishimaru, "Optical scattering and diffusion in turbulence and scatterers," OSA Meeting, San Francisco, October 1978.
2. K. Shimizu and A. Ishimaru, "Estimation of size distribution of randomly distributed scatterers," OSA Meeting, San Francisco, October 1978.
3. A. Ishimaru, "Forward scatter and diffusion of pulses in a random distribution of scatterers," URSI Meeting, Boulder, November 1978.
4. A. Ishimaru, "Multiple scattering effects on pulse propagation through fog and clouds," Naval Ocean Systems Center Program Review, San Diego, November 1978.
5. A. Ishimaru, "Forward scatter theory and diffusion theory for wave in random media," Bremmer Session, National Radio Science Meeting, Seattle, June 1979.
6. A. Ishimaru, "Multiple scattering effects on backscattering of a pulse from terrain," National Radio Science Meeting, Seattle, June 1979.
7. K. J. Painter and A. Ishimaru, "Backscattered pulse shape due to small-angle multiple scattering from a slab of random medium," National Radio Science Meeting, Seattle, June 1979.
8. K. Shimizu, A. Ishimaru, and A. P. Bruckner, "Backscattering of a picosecond pulse from a dense scattering medium," National Radio Science Meeting, Seattle, June 1979.
9. R. L.-T. Cheung and A. Ishimaru, "Multiple scattering of millimeter waves in rain," National Radio Science Meeting, Seattle, June 1979.
10. A. Ishimaru was invited to speak at the Chemical Systems Laboratory Scientific Conference on Obscuration and Aerosol Research, U.S. Army, Aberdeen Proving Ground, Maryland, September 1979.
11. K. Shimizu, A. Ishimaru, and L. Reynolds, "Diffusion and scattering of a picosecond pulse in a dense scattering medium," OSA Meeting, Rochester, October 1979.
12. A. Ishimaru was invited to speak on "Theoretical and experimental study of transient phenomena in random media" at the workshop on "Wave Propagation in Turbulent Media" sponsored by the Mathematics Division, U.S. Army Research Office, at Virginia Polytechnic Institute, Virginia, March 24-27, 1980.

6. Publications - continued

Paper Presentations Related to the Contract Since September 1978

13. A. Ishimaru and R. L.-T. Cheung, "Multiple scattering effects on wave propagation due to rain," URSI Commission F Symposium, Lennoxville, Canada, May 1980.
14. A. Ishimaru, R. L.-T. Cheung, and Y. Kuga, "Diffusion of a beam wave in random discrete scatterers," North American Radio Science Meeting, Quebec, June 1980.
15. A. Ishimaru, "Characterization and remote-sensing of terrain," ICC '80, Seattle, June 1980.
16. A. Ishimaru, "Pulse propagation and diffusion in random media," International URSI Symposium on Electromagnetic Waves, Munich, August 1980.
17. A. Ishimaru and R. L.-T. Cheung, "Incoherent intensities due to rain," National Radio Science Meeting, Boulder, January 1981.
18. A. Ishimaru, "Multiple scattering effects on optical propagation in turbulence and particles," NATO-AGARD Meeting, Monterey, California, April 1981.
19. Y. Kuga and A. Ishimaru, "Attenuation constant of coherent field in dense spherical particles," National Radio Science Meeting, Los Angeles, June 1981.
20. R. L.-T. Cheung and A. Ishimaru, "Transmission and backscattering of optical waves through fog," National Radio Science Meeting, Los Angeles, June 1981.
21. A. Ishimaru, "Multiple scattering in turbulence, scatterers, and rough surfaces," URSI Symposium on Mathematical Models of Radio Propagation, Washington, DC, August 1981.
22. R. L.-T. Cheung, "Millimeter and optical waves in rain and fog," Ph.D. Dissertation, Electrical Engineering Department, University of Washington, December 1981.
23. A. Ishimaru and R. L.-T. Cheung, "Transmission, backscattering, and depolarization of waves in randomly distributed spherical particles," National Radio Science Meeting, Albuquerque, May 1982.
24. A. Ishimaru, "Frequency spectra of ultrasound pulses reflected from scattering medium," 7th International Symposium on Ultrasonic Imaging and Tissue Characterization, NBS, Gaithersburg, Maryland, June 1982.

6. Publications - continued

Paper Presentations Related to the Contract Since September 1978

25. J. Machado, R. A. Sigelmann, and A. Ishimaru, "Experimental and theoretical study of phase and amplitude of ultrasonic waves through random medium," 7th International Symposium on Ultrasonic Imaging and Tissue Characterization, NBS, Gaithersburg, Maryland, June 1982.
26. A. Ishimaru, "Introduction to the theory and application of wave propagation and scattering in random media," SPIE (International Society for Optical Engineering) Meeting on Applications of Mathematics in Modern Optics, San Diego, August 1982.
27. A. Ishimaru, "Scattering of Electromagnetic Waves in a Random Distribution of Nonspherical Particles," International URSI Symposium on Electromagnetic Theory, Santiago de Compostela, Spain, August 1983.

7. Remaining Funds

No unspent funds remaining at the end of the current contract period.

8. Personnel

Graduate Students:

- (a) Koichi Shimizu
- (b) Raymond Chan
- (c) João Machado
- (d) Kirk Painter
- (e) Rudolf Cheung
- (f) Yasuo Kuga
- (g) H. W. Chang

9. Graduate Students Who Have Earned Advanced Degrees

- (a) Kirk Painter, M.S. in E.E., Fall 1978
- (b) Koichi Shimizu, Ph.D. in E.E., Summer 1979
- (c) Raymond Chan, M.S. in E.E., Fall 1980
- (d) Rudolf Cheung, Ph.D. in E.E., Fall 1981

10. Other Government-Sponsored Research

Title: Wave Propagation in Dense Geophysical Media

Grant No.: DAA G29-81-K-0065

Agency: ARO

Term: April 1, 1983 to March 31, 1984

Funding: \$49,810

Principal Investigator: Akira Ishimaru

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